STUDIES

ON THE

NORTH AMERICAN LAKES,

AND

ESPECIALLY UPON THE DRIFT FORMATION IN THE MAUMEE VALLEY AND UPON THE SOUTHERN SHORES OF LAKES ERIE AND MICHIGAN; TOGETHER WITH THE CONNEXION OF THE FEATURES PRESENTED IN THESE LOCALITIES WITH THE GEOLOGICAL HISTORY OF THE LAKES.

INAUGURAL - DISSERTATION

FOR THE

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AT THE

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BY

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In presenting this article to a highly distinguished philosophical faculty as an inaugaral dissertation for the degree of Doctor of Philosophy, it affords me pleasure to gratefully acknowledge my obligations to the honored members of it, whose lectures and exercises I have attended; and I acknowledge my special indebtedness for friendly advice and assistance to Professor Sartorius von Waltershausen and Professor Wöhler.

(1) Few localities present a more attractive field to the student of Physical Geology than the North American Lakes, and the country included in the so called „Lake Basin." These lakes lie between the 41st. and 49th. parallels of N. latitude; and the 76 and 92 meridians of W. longitude. The entire area of the Lake Basin — in which is included all the country drained by the St. Lawrence river — comprises 297600 square miles. Of this area, the water surface of the lakes themselves occupies 93,060 square miles as follows:

Lake Superior	32000
„ Michigan	24400
„ Huron	20400
„ St. Clair	360
„ Erie	9600
„ Ontario	6300
Total	93,060

This leaves 204540 square miles of land surface. The large proportionate amount of water surface is a characteristic feature of this basin; and in the upper part, where the lakes themselves are situated, the proportion of water to land surface is even greater. Lake Superior is the largest body of fresh water on the globe. It empties into Lake Huron through its outlet, the St. Mary's river. Lake Huron also receives the waters of Lake Michigan through Mackinaw Straits, and thus becomes the reservoir for the waters of two great lakes. It flows through the St. Clair river into the small body of water, Lake St. Clair, which

empties into Lake Michigan through the Detroit river. Lake Erie flows into Ontario through the famous Niagara, whose falls form a feature of surpassing grandeur and interest, and present an interesting subject of study to the student. The St. Lawrence river forms the direct outlet of Lake Ontario, as well as the real outlet of all the others; and thus their waters pass into the Gulf of St. Lawrence, and thence into the Atlantic.

The elevations of these lakes above the level of the sea are respectively:

Superior	627	feet				
Michigan	578	„	(49	feet	belon	Superior)
Huron	573	„	(5	„	„	Michigan)
St. Clair	570	„	(3	„	„	Huron)
Erie	564	„	(6	„	„	St. Clair)
Ontario	234	„	(330	„	„	Erie.)

The figures in the above table may serve to give a correct idea of the character of the outlets of the several members. St. Mary's river has rapids, having to descend 54 feet in its course; and the Falls of Niagara are too well known to need mentioning. The remainder of the outlets have little descent and hence, a gentle current.

The region which it is the principle object of this paper to describe, lies upon the south western shore of Lake Erie, and extends in a westerly direction to Lake Michigan. Other localities, whose features bear upon those of the region mentioned, may also be noticed. The region in question is underlaid by rocks of the Devonian and Silurian Ages. But in very few localities are the underlying strata exposed on the surface. They are covered with layers of drift material, more or less modified by the action of subsequent agencies. In many parts, as will be hereafter mentioned, boulders are found in connexion with the strata of sand, clay, gravel, etc. These boulders are of granit, syenite, trap, sandstone and limestone; in short of the same material as the rocks now found to the north. An exceedingly interesting fact is, that copper nuggets

have been found as far south as the southern shore of Lake Erie; thus unmistakably pointing to the Lake Superior veins as the source of their origin, and leaving geologists to study the means by which their transportation was effected.

With this brief outline of the general features of the „Lake Basin", we will next proceed to describe the special features of those parts chosen as our subject, after which some general conclusions will be drawn relative to the geological significance of the observations upon the physical history of the lakes.

Most of the observations upon the special localities are my own, and have not been hitherto published, so far as my knowledge extends.

Physical Features of the Maumee Valley.

(2) The region drained by the Maumee and its branches is full of interest, as bearing upon the question of the former level of the lakes, and of the formation of land surface having a widely different kind of soil, and supporting almost totally different kinds of vegetation. The Maumee, as will be seen by consulting the map, is the principle southwestern tributary of Lake Erie. Its basin comprises an area of about seven thousand five hundred square miles. The section of country composing the Maumee Valley is remarkably level. Hills are almost unknown. This feature is so prominent, that the construction of railroads through this country is an exceedingly easy matter. The streams are usually sluggish and hence winding in their courses. This feature is partially due to the fallen timber which obstructs the free passage of the waters of their channels, but mainly to the gentle declivity of the country towards the lake. The river itself has a somewhat

sluggish current for most of its course; but towards its mouth a series of rapids, in which it descends about sixty feet in five miles, compensates for its previously slow motion. The surface of this valley is divided into two entirely different classes of land. The first is covered with a dense growth of tall timber, comprising beach, oak, ash, maple, hickory, walnut, sycamore, and other kinds, and also with a heavy growth of under vegetation. The soil consists of a layer of vegetable mould, a few inches in thickness, and underlaid by a stratum of clay, varying from yellow to blue, and of such consistence and hardness that it is almost impermeable to water; and in sinking wells, this layer must be cut away with an axe. When parched by the drought of summer, this clay forms blocks nearly as hard as limestone. This property renders the country exceedingly wet during the rainy months; and at these seasons the surface water, unable to penetrate the clay layer, is compelled to pass off by means of the streams, and hence result inundations of a greater or less extent. After passing through the clay layer, a stratum of quicksand is encountered, succeeded by another layer of clay. Boulders are very seldom found in this region, and with very few exceptions, there are no surface rocks, and none within the distance of one hundred feet. This latter fact has been established by boring for artesian wells. The wells, unless of the class just mentionel, fail during the dry summer months. The second class of land, called „openings“, comprises a tract covered with a thin growth of small oak timber. In many places this thin growth of timber is replaced, at least partially, by a dense covering of oak shrubs from ten to twenty feet in height; and which forms an almost impenetrable thicket. The soil is thin and sandy, producing but poor crops, and presents in this respect a marked contrast to the fertile and productive soil of the timbered land. It is but sparsely settled, and for many years must remain so. After descending through the sandy surface, a „hardpan“ is encountered, followed by

another layer of sand; this is underlaid by a layer of gravel, after which the clay layer is struck. Many of the creeks which run through these „openings“ have worn their way through the layers of dry sand and hardpan to the quicksand layer, and hence they are marshy, and in the wet seasons impossible to be crossed. These openings consist of ridges of sand alternating with low, wet marshes. The marshes are an interesting feature. They are usually but a few rods in diameter, and occur in chains parallel to the ridges. They are connected by outlets with each other; but the outlets are shallow compared with the ponds themselves, and hence the latter are not drained, but contain water during most of the year. In the dry season they are frequently parched, and the black, loamy soil is cracked and dried. These little ponds are covered upon their borders by a dense growth of coarse grass, and further towards their centers they support a heavy covering of rushes and pond lillies. The general direction of these series of ponds is parallel to the ridges, and these are in turn parallel to the timbered land. Thus the country is divided into successive bands of sandy openings and clayey timbered land, each several miles in width. The general direction of these bands is parallel to the shore of the lake, and to the Maumee river. The significance of this fact we shall soon see.

(3) The gradual merging of these bands of openings and timbered land into each other is an interesting fact. The change is equally gradual in the character and external appearance of the soil, and in that of the vegetation. As one approaches the edge of a belt of timbered land from the openings, he notices that the oaks begin to increase both in size and number. The thick covering of oak shrubs also begins to disappear. Just before the timbered land is reached the oak timber increases to such an extent as to form a splendid covering of tall and straight trees. Then commences the variety of trees previously

mentioned in connexion with the timbered land. The change in the character of the soil is equally remarkable. The barren, yellow sand begins to assume a more loamy character; the hardpan subsoil passes gradually into a mixture of clay and sand; and thus the features characteristic of the surface and underlying strata of both sections pass almost insensibly into each other. These distinguishing features of the soil are not produced by the cropping out of continuous and underlying strata, after the manner of rock formations. They consist of layers, extending in comparatively narrow bands or belts, which were deposited in this way, and under such circumstances and conditions as gave them their characteristic features, and caused them thus gradually to blend into each other.

(4) In some parts of this section the ponds, previously mentioned as occurring in the openings, expand into large, wet prairies of several square miles in extent. In these cases, they are covered with water to a depth of from a foot to eighteen inches during a large part of the year; and it is very seldom that they are entirely dry in the hot summer months. The vegetation with which they are covered corresponds very nearly to that of the small ponds previously noticed. In some cases the transition from the swampy ground of these marshy prairies to the dry and sandy land which surrounds them, is quite gradual; while in other instances, one ascends directly from them to the low and sandy hills of the higher land. The surface soil of these low marshes is a black muck about eighteen inches in thickness, and formed, undoubtedly, by the continued decomposition of vegetable matter during a long succession of years. The subsoil consists of a coarse, waterwashed gravel, entirely similar to that found in the ridges at a depth of ten to twelve feet below the surface, and also to the gravel now found upon the beaches of Lakes Erie and Michigan.

(5) The absence of boulders, as well as of stratified rocks over a large area of this section of country, has already been noticed. One very remarkable exception occurs in the eastern part of the tract, and about five miles from the Maumee river. A ridge is found in this locality, which rises but little above the surrounding country, but which is composed of regular strata of limestone which crops out at the surface. This remarkable ridge is about an eighth of a mile in width and several miles in length. It is resorted to for many miles distance to obtain stone for building purposes, and also for lime, the want of both of which is deeply felt over the entire region. The geological significance of this feature will be spoken of hereafter.

(6) In the southern part of the Maumee Valley lies a large tract of country, in which the alternate bands of openings and timbered land give place to one unbroken extent of very heavily timbered country. To this tract the name „Black Swamp“ has been applied. The surface is eminently characterized by excessive flatness. This feature, added to the covering of trees and bushes which it bears, and which are almost impervious to the sun's rays, tend to make the surface moist, and in the rainy seasons almost impassably muddy; from which circumstance it derives its name. A large portion of this section is drained by the Tiffin and St. Mary's rivers. The soil is quite similar to that of the timbered land previously mentioned, except that the substratum of clay is sometimes blue and at other times yellow. It is interesting to observe the effect which the clearing of this tract effects in the character of its surface. When the natural covering of timber is removed, and the fallen timber, which has obstructed the channels of the streams, is taken away, the face of the country presents an aspect as different from its natural condition as is the appearance of modern Germany from that which it presented in the times of the Roman empire. Evaporation proceeds with so much greater rapidity from the cleared

than from the timbered surface, that the fields are sufficiently dry for agricultural purposes; and the roads, which previously were almost impassable, then become good. This simple fact illustrates the immense power which man exercises over physical laws, and the extent to which his action may modify the natural features of a region, and even to some extent natural laws. This section is near the southern limits of the drift formation, and like the sections already described, is remarkably free from boulders. When passing through it, and reflecting upon its extremely flat surface, upon its relative position to the lake, and upon other geological facts which may be elicited in the course of this paper, one can hardly resist the conclusion, that this tract once formed a large bay, tributary to Lake Erie, and that the evenness of its surface is largely due to the quiet deposition of drift material in a body of shallow water, sheltered from rapid currents, and to some extent from sweeping winds and waves.

(7) An interesting feature connected with the surface of northwestern Ohio is, the great number of artesian wells which it affords, and the ease with which they are generally obtained. At Bryan, Williams Co, especially are these wells obtained with little effort. The only thing necessary is, to sink a shaft to depths varying from fifteen to twenty feet. A vein of water is then usually struck, which gushes up through a tube driven into the hole obtained by boring. The water rises to heights varying with the elevation of the surface where the well is sunk. In some places jets are thrown up to a height of three or four feet above the surface; in others, the water does not come quite up to the level of the ground, but remains stationary a few feet below. The water in the various wells in this immediate vicinity rises to the same general level. This proves that they are dependent upon one common source for their supply. Another striking proof of this mutual dependence occurred at Bryan a few years since. A well was sunk in

the lower part of the town. The water rose with immense force, and flowed out in large quantities, much surpassing the previous outflow of the other wells. The result was, that the flow of many of the wells in the neighborhood was either greatly diminished. or entirely stopped; and it was found necessary to stop the flowing of the new well, at no small amount of effort, before the damage could be remedied. The quantity of water thrown out by these artesian wells is very great, and the outflow is not sensibly affected by the season of the year, and not in the slightest perceptible degree by heavy showers. At a distance of thirty to fourty miles east from Bryan, and upon ground of a considerably less elevation, artesian wells have been sunk to depths of seventy five to one hundred and fifty feet. In no case has the water flowed over the surface; but in many instances it has risen to within a few feet of it, and has maintained this level at all seasons of the year. In this locality many shafts have been sunk without finding water. Borings which have reached considerably below the level of neighboring and successful ones, have frequently proved unsuccessful. The same fact is also observed at the distance of only a few miles from Bryan. At Toledo, on the very brink of the lake, an artesian well was sunk to a depth considerably greater than those last mentioned, before a supply of water was obtained. These facts seem to show that subterranean streams of considerable size are numerous in this section; that they flow in streams or channels, as is shown by the unsuccessful attempts at finding water; and that these channels flow at varying depths beneath the ground. It would also seem that, as we approach the lake from Bryan, the subterranean streams sink deeper into the ground; but many more observations are necessary before this can be safely affirmed as a general statement. The water of the wells is largely impregnated with iron.

(8) As we proceed a little north of west towards the

southern extremity of Lake Michigan, some of the features belonging to the Maumee Valley undergo a change. The country is still divided into the two principal classes, openings and timbered land, but the difference in the two classes is much less marked. The timber found upon the two is much more equal in quantity, and alike in specific character. The openings and timbered land do not appear so distinctly in alternate belts as in the Maumee Valley, nor do they seem to follow any definite direction. But there are two features which especially distinguish this section from that previously described. First, the ponds of the former here expand into little lakes of considerable extent, but not of great depth, not exceeding ten or twelve feet usually. Secondly, boulders are found in considerable numbers. These are not of large size, seldom exceeding two to three feet in diameter, nor are they so numerous as to offer serious obstructions to agricultural pursuits; but yet their presence in a region northwest of the Maumee Valley is an instructive fact, and one from which interesting deductions may be drawn. As we approach the shore of Lake Michigan, a series of new features are presented, which are described more fully in (11)

(9) The tract of country lying north of the Maumee Valley, and included mostly in the state of Michigan, presents much the same features as those mentioned in the preceding section. But the characteristic features of that tract, and which distinguish it from the Maumee Valley, are here much more strongly marked. The same subdivision of the surface as regards the distribution of timber is observed, until a latitude sufficiently north is reached for the appearance of the pine. But the boulders are found in such numbers as to form a serious obstacle to the agriculturalist. They are frequently found of large size, ten feet and more in diameter. The most characteristic feature of this section is the great number of little lakes which are distributed over it. These are frequently of a diameter of from

one to two miles. They are usually quite deep, sometimes reaching one hundred feet; and in some cases no bottom has been found, owing to the imperfect means at hand for ascertaining the depth. They are not fed by inlets, in many cases; but form the sources of streams. Their outlets are usually quite small compared with the lake itself. In one instance, the lake is one and a fourth miles in length and three fourths of a mile in breadth, and of unknown depth; the outlet is about four feet in width, and perhaps two in depth. The borders of these lakes are usually low, and covered with a dense growth of tamarac; but sometimes high banks, composed of sand and boulders, rise directly from the water's edge. Frequently the shallow parts of the lake are filled with aquatic plants, which grow so thickly as to almost afford a firm footing. There can be no doubt that the annual growth and decay of these plants will, at length, form a soil sufficient to support a growth of the tamarac; and that thus the lake itself is undergoing a slow, but constant, process of filling up.

(10) The facts mentioned in the previous section and in (2) and (8) furnish material for the enunciation of a general principle respecting the relative distribution of boulders, and the occurrence of ponds and lakes of greater or less area and depth. This principle may be stated as follows: The volume of water contained in the lesser lakes of the Drift Formation in the region described, is proportional to the quantity of boulders found upon, or near the surface. Thus, in the Maumee Valley, with an almost entire absence of boulders, the lakes are reduced to mere ponds; farther to the northwest an increase of both is observed; while in the section last described, each feature appears fully developed.

(11) Before leaving the description of this part of the drift formation, it will be necessary for our purpose to speak of the features presented upon the southern shores

of Lake Michigan, since these features stand in intimate relation to those already described. The shores referred to, consist of a series of sand dunes. Along the southern and south eastern shores of this lake, for a distance of many miles from the water, dunes extend. They are covered with a thin growth of low pines, which can scarcely find nourishment in the almost desert soil from whence they spring. The coarse, white sand supports scarcely any other vegetation; and the aspect of these dunes is that of a sand plain upon which a few shrubby trunks manage to subsist. These sand hills are interspersed with ponds of water. The limits of both hills or ridges, and that of ponds, is undergoing an almost constant change on account of the ease with which the wind carries the dry sand along with it; and also by means of the degrading or leveling influence of precipitation. As we recede for a considerable distance from the lake, these barren hills gradually merge into more fertile ones; the country assumes a more hospitable appearance; and supports a richer vegetation. But the ponds yet remain characteristic. For some distance to the south they are found in considerable numbers; and proceeding to the east and south-east, we pass over the country described in the preceding sections, and where their occurrence and peculiar features have been mentioned. Upon the southern shore of the lake, the sand hills attain but a slight elevation, and the immediate shore rises but a few feet above the surface of the water, which almost constantly beats against it. But as we proceed to the north, on either the eastern or western shore, the banks are much higher. These two shores, however, present a widely different appearance. That upon the west consists of alternating layers of clay, sand, and gravel, which usually rise precipitously from the water's edge; and which are constantly being undermined and washed away by the waters of the lake. In many places, very complete sections of the strata are presented as one approaches the shore from the lake, and excellent opportunities are thus afforded for investi-

gating their character and structure. These sections reveal the fact that the western shore of the lake, for the greater part of its length, consists of stratified layers of drift material, as clay of various colors, and mixed with sand to a greater or less extent, gravel, sand and hardpan. Upon the eastern shore we also have sand banks of great elevation; but here we find them not undergoing a process of degradation, but one of constant accumulation. The structure of these sand hills is an interesting subject of study. The prevailing direction of the winds in this region is from the west, and north, especially the former; and hence, during most of the time, the waves beat upon the eastern and southern shores. The action of the water upon the particles of sand which lie upon the bottom of the gradually sloping shore, tends to carry them towards the land, und thus a small quantity of sand is almost constantly transported to the beach. As soon as the particles are out of reach of the force of the receding wave, the wind aids in their transportation landward, and they thus become a part of these barren but interesting dunes. Where the winds are strongest, other things being equal, we would expect to find the highest hills. We find this condition fulfilled upon the eastern shore, and the anticipated result is also present. Around Grand Haven, and other places upon this shore, the sand hills rise to a height of several hundred feet, and present an aspect forlorn and dreary indeed, but yet beautiful when we consider their symmetry; and grand, when we contemplate the forces which operate in their formation. The hills at Grand Haven rise gradually from near the water's edge. The slope towards the lake is somewhat irregular, but that upon the land side is nearly straight. The slope descends with scarcely an irregularity from top to bottom. Upon many of these hills, not a tree, shrub or plant finds an abode; the slope of clean, white sand is uninterrupted. Almost constantly may be noticed the descent of small quantities of sand down the slope. The cause of this regularity of figure is easily

seen. As the particle of sand is driven up the seaward slope by the force of the wind, it reaches the summit, and as it passes the crest and finds itself upon the landward slope, it is protected from the further influence of the wind by the ridge itself. It is thus left free to the action of gravitation and precipitation. This latter force is of little moment, since the rains are driven with much the greater force upon the western side; and the constancy of the almost exclusively acting force of gravity tends to give the eastern or leeward slope that symmetry which so strongly contributes to make these hills an object of much interest.

Character of the floor or bottom of Lake Michigan.

(12) A most interesting series of facts has been brought to light by the prosecution of the work known as the Chicago Tunnel. This is an arrangement for the purpose of supplying the city with water from the lake. For this purpose a coffer dam was erected in the lake, at a distance of two miles from the shore. A shaft was then sunk within this dam, to a depth of seventy five feet in the floor of the lake. Upon the shore, a similar shaft was sunk; and the bottom of these shafts was then connected by means of a horizontal shaft, running under the bed of the lake. A fine opportunity was thus afforded for observing the character of the formations thus penetrated. The vertical shaft on the shore descended first through a layer of beach sand, and then through one of tough clay; both layers apparently being the work of lake deposition. Immediately below this was a layer of the glacial drift, containing boulders. This layer consisted mostly of clay which seemed to have been reduced from shale, by means of erosion. The boulders bore marks of glacier scratches, and consisted of limestone, sandstone, granite, syenite, and other species of rock, all of which are now found in the regions north. The horizontal shaft revealed some facts of extra-

ordinary interest. A stratum of sand only six inches in thickness and underlaid by a bed of clay, was traced for a distance of more than a thousand feet, where it ascended and disappeared above the roof of the shaft. Another stratum of sand was soon after struck, whose upper surface showed ripple marks distinctly. Even the clay which rested upon this layer of ripple-marked sand, showed a perfect cast of the ripple marks, when the sand was removed from beneath it. After tracing this stratum for about fifty feet, it thinned out and disappeared. Further along, two layers of clay were struck, and traced to a distance of four thousand feet to the end of the horizontal shaft. Throughout the layers which contained boulders, were found numerous examples of what were termed „pockets". These „pockets" consist of cavities in the clay, from a few inches to several feet in diameter, and filled with perfectly clean gravel arranged in thin stratified layers, which lay at all angles with the horizontal. The pockets also usually contained a quantity of water in their lower parts; and some air, or in some instances, inflammable gas, in their upper parts. This fact is accounted for upon the theory of the decomposition of highly bituminous limestone, found in the clay, while the cause of the pockets themselves is sought for in the hypothesis, that they were deposited as frozen masses of gravel, and thawed after being well imbedded in the clay. Their strata would thus be left in whatever position they chanced to be in, when frozen. — Not the slightest trace of organic remains were found, after penetrating beneath the deposits made by the lake itself. (See American Journal of Science, Vol. XLIII, p. 75.) These facts show that layers of drift material extend for some distance beneath the waters of the southern part of Lake Michigan. The additional facts mentioned, that sand dunes extend along the eastern shore of the lake, and upon the western coast, sand and clay strata alternate, show that it is highly probable that the bottom of the lake in these localities also consists of the same material.

(13) The Mineral Springs at Castalia are another highly interesting feature connected with the lakes. They are situated about five miles from the shore of Lake Erie, and eight nearly south from Sandusky City, Ohio. The outcropping rocks belong to the Devonian Age, Corniferous Period, and probably the upper Helderberg Epoch. A new geological survey of the state of Ohio is necessary for a more accurate acquaintance with its minor stratigraphical features; the Report being nearly thirty years old, and not including the entire state. The shore of Lake Erie in the vicinity of Sandusky City is greatly indented and broken up into projections and indentations. At a short distance from the shore, islands occur in the lake. — The springs are two in number. The upper one is situated at the foot of a slightly elevated sand ridge. It is about twenty five feet in diameter, and ten feet in depth. The water gushes out from crevices in the rocky sides and bottom, keeping the large channel which flows from the spring constantly full. At a distance of a quarter of a mile below, the original channel has been dammed, and a large portion of the water has thus been diverted from its original course for industrial purposes, and made to unite its waters with those of the lower spring, thus forming a long pond. This is filled with vegetation, the growth of which is stimulated by the copious mineral ingredients of the spring water; and consists mostly of algae. The mode of growth of these plants is highly interesting. They commence in collections of minute organisms, which form in some of the recesses of the pond, and continue to increase in area and depth. They soon become so large that they extend from the sheltered spot where they commenced their formation, toward the middle of the stream. The saturated water continues to nourish the newly formed vegetation, and thus a floating island is formed, a number of which are now in the ponds, some of them having a diameter of several rods. The continued growth of the vegetation, and the constant deposition of mineral matter, will ere long cause them to

settle, until they find a resting place upon the bottom of the pond. Others will in turn originate, float for a time, and become settled: and thus the bottom of the channel is rapidly becoming filled. This process will continue until the present channel becomes entirely filled, when the spring will find a new outlet, which in turn will gradually be obliterated; and thus the process will continue, until it will raise the land around the spring to such a height, that an overflow of its waters will cease to take place. A small portion of the water of this spring still overflows the dam previously mentioned, and flows in its original channel, along the borders of a large marsh, a part of its waters infiltrating the soil.

(14) The lower spring is situated half a mile below the one just mentioned. It is somewhat larger in diameter, and fifty to sixty feet in depth. Its water is remarkably clear, so that quite small objects may be seen lying upon the bottom. The sides are almost perpendicular; and a trunk of a tree lies in it, doubtless completely petrified. Immediately below, and at a distance of only a few rods, a dam has been thrown across the channel of the stream, and the water is forced through a mill race. The surface of the pond is thus raised above the banks of the lower spring, so that its waters, instead of flowing directly away in a channel, spread out on all sides, and at once mingle with the waters of the pond. Vapors of Sulphuretted Hydroyen are emitted from both springs. The temperature was about 15° C.; but as a large quantity of water confined by means of dams, is brought in immediate mixture with the spring water, the temperature of the latter would doubtless be much higher, if unmixed. The springs do not freeze in winter. This fact, considering their comparatively low temperature, is worthy of note, and can readily be accounted for, by the powerful current which could with difficulty be confined by a layer of ice. The mineral ingredients consist of Carbonate and Sulphate of Lime, with

a trace of Protoxide of Iron. Some of the first explorers of the section, half a century ago, stated that the springs were quite warm, and that the upper one sent up a column of water considerably elevated in the center; but these statements must be received with great caution. It is highly improbable that their character should have been materially modified in either of the above respects in so short a period, although slight changes may have taken place. The amount of water thrown out by these springs is enormous, amounting to over one million of cubic feet per hour. This would be equal to an annual outflow of a lake, having an area of one hundred square miles, and a depth of four feet. The upper spring throws out a little more than the lower one. The immense amount of earthy matter thus abstracted from beneath the surface in the neighborhood, or from the same source from which the earthy matter comes, thus forms no mean undermining power. From a calculation, based upon the amount of mineral matter held in solution by a small quantity of the water which was brought to Göttingen, I find that upwards of one hundred thousand cubic yards of earthy matter are annually abstracted from the earth's interior, by the agency of these springs. The results of this continual abstraction are seen in the immediate neighborhood of the spring, in the form of „sink holes". These consist of depressions in the surface, reaching to a depth of twenty to thirty feet. They have no outlets: their sides are inclined at various angles with the vertical, sometimes as high as 45°. Some of them are quite large, including over an acre. They have every appearance of having fallen in from the surface. — The greater part of the waters of the springs flows into the lake; while the remainder empties into the adjoining marsh, several square miles in extent, and consisting of calcareous tufa, the result of the agency of the earthy matter held in solution.

(15) Among the many interesting features in the neighbor-

hood of these springs the following are most worthy of notice: — (1) The Marsh. This is several square miles in area. The surface is covered with coarse grass, moss and rushes, rapidly undergoing petrifaction. The upper layer of soil consists of calcareous tufa, in which the fragments of stems of rushes, of moss, and of fresh water shells are found very distinctly preserved. In the higher parts of the marsh are found incrustations of tolerably pure Carbonate of Lime, more nearly approaching Travertin. The borders of the marsh are formed of partially decomposed tufa, overlaid with a sandy soil, thus leaving no doubt that its area was formerly much greater than at present. A shaft sunk towards the center of the marsh for a distance of a few feet, reveals the remarkable fact that the ground is composed of a series of alternate layers of calcareous tufa and vegetable mould, the former of which were evidently deposited by the same agency as that which is now in progress. The question at once arises respecting the cause of this fact. It is evident that the agency of the water of the springs could not have been exercised as now during the deposition of these layers of vegetable mould. This can be accounted for upon either of two hypotheses. (1) The springs may have been intermittent during long periods of time, such as would be necessary for the formation of layers of tufa or mould from one to two feet in thickness. Their waters may have ceased to flow during the formation of the vegetation which formed the mould; or the amount of water which they furnished during these periods may have been diminished in quantity, so that it was carried off to the lake in its channel, no surplus remaining to overflow its banks and cover the marsh while the vegetable mould was in process of formation. (2) The comparative level of the lakes and the shore may have changed with reference to each other; the shore, together with the marsh undergoing a depression sufficient to cover the marsh with a thin covering of the water of the lake, sufficient to support the growth of an extensive covering of aquatic

plants, whose annual decay furnished the mould. In this latter case, the waters of the spring would become mixed with an immensely greater proportion of lake water, free to a great extent from mineral ingredients, and they would thus become so largely diluted, as no longer to operate in the manner which now characterizes them. The latter hypothesis is much more in harmony with observed geological facts. Alternate elevations and depressions of surface are common places in Geology; while the suspension of the operation of a mineral spring for a long period of years, followed by a period of activity for a corresponding period, are phenomena not yet recorded in geological observation. (2) A noticable feature of the springs is, the rapidity with which their waters petrify organisms with which they come in contact. Just below the dam, a thick growth of moss has been induced by the rich mineral ingredients of the water. The lower parts of the moss are perfectly petrified; the middle parts only partially; while the upper parts are in process of rapid growth. A vertical section shows every possible gradation from complete petrifaction to perfect life. Even the mill wheels are petrified by the water which falls upon them; and they thus become imperishable. (3) The rocks are exposed over a considerable area between the springs and the lake. The drift material in such localities has been swept away. In many places, the slightly dipping strata of rocks are covered by a layer of soil of but a few inches in thickness, and incapable of supporting a healthy vegetation, during the hot and dry summer months. At such times the vegetation becomes parched. The idea naturally suggests itself, that copious springs ought to be expected in localities like this, where the rocks have been subject to disturbing influences; and where the egress of the subterranean streams is unimpeded by a covering of drift material. (4) There is every reason to believe that the bottom of the bay at Sandusky is penetrated by several springs similar to those at Castalia. It has long been noticed that in certain spots, during the winter, air holes

of large size are uniformly found in the ice. In the coldest winters they are not frozen over. The only way of accounting for them is, to suppose that each of these air holes represents a spring of about the same temperature as those at Castalia; and hence incapable of being frozen over. This assumed, another evidence is furnished of fracture in the surface of the lake border in this region. The amount of water necessary to preserve open places in a body of water of the size of the bay, must be very great, and the force with which it presses its way upward through the mass of water above it, must be a strong one. (5) The gypsum beds. These are situated about ten miles to the N. E. So far as known, they occupy about one hundred square miles of surface. Sixteen thousand tons were sold from them in a single year. The dip of the rocks is here from 2—5° east, the strata cropping out towards the west, so that the stratum from which the springs issue, is beneath the gypsum beds. This fact will easily account for the presence of sulphur in the waters of the springs. The gypsum beds alternate with strata of silicious and argillaceous shales from one to six feet in thickness, and are from two to seven feet thick. In some instances, the gypsum penetrates the strata, and at other times extends into it for some distance. This fact would seem to indicate that the gypsum was not the product of mere deposition, but that disturbing forces were in progress during its formation. There are numerous localities of gypsum along the shores of several of these lakes; and if the theory of the igneous origin of this mineral be accepted, their presence shows that these bodies of water have been the scene of extended disturbance. The gypsum is not crystallized but somewhat columnar; and is considerably whiter than is usually the case. (6) The fossils in the rocks exposed at Sandusky are numerous. The genera Favosites, Cyathophyllum, Spirifer, Productus, Leptaena and others are well represented. Fossil fishes are also found; their estimated length reaching seven feet; and that of a tooth,

one inch. The remains of a mammoth were excavated from the drift deposits a few years since, a short distance from Sandusky City; and quite a number of such cases have occurred upon this shore of the lake. — Heavy Spar and Celestine are found abundantly upon the neighboring islands. These islands furnish numerous evidences of glacier action. They are undergoing a gradual process of erosion by the lake currents; and the inference seems to be warranted, that the long continued eroding action has very greatly lessened an area of land surface which was formerley much greater, and which perhaps extended over no small part of this end of the lake.

(16) Having thus described the more important features which are presented in the regions under consideration, it remains to notice the bearing which the facts cited have upon the physical history of the lakes: and to deduce such theoretical conclusions as may seem naturally to result. The most important questions for solution are: — The Former Level of the Lakes; has it always been materially the same as now; or has it suffered a constant and gradual diminution; or has it been subject to alternate elevating and sinking processes? If either of these two latter alternatives be true, has the diminution of their volume of water resulted from the sinking of the bottom of the lakes; or from the draining off of the remains of the former universal ocean; or from the upheaval of their banks? It is indeed not the province of this dissertation to attempt the solution of these great questions or any of them. They have already been the subject of discussion between many of the ablest geologists. But yet there are facts among those mentioned which bear upon a number of these points; and which possibly may add slightly to the probabilities of the truth of one or more of the alternatives. (1) Significance of the bands of openings and timbered land in N. W. Ohio. It is now very generally agreed by American geologists that, during the Drift Period,

the Northern parts of the United States were covered with immense masses of ice, boulders and other drift material, for a depth of several thousand feet; that this icy covering was attaked upon its southern side by the heat of the sun, and hence commenced wasting away towards the south; that by this action, currents were formed, which worked the transportation of boulders imbedded in ice, as well as effected the crushing of many of them, and of the rocks upon which they impinged, and thus produced the finer drift material. The question now arises, — could the bands of soil, which characterize the openings and timbered land above mentioned, have been produced by this agency alone? In reply to this question, it need only be said, that formations of bands of such regularity, and whose presence testify most clearly to the action of a gradual, slowly acting, long continued and uniform cause, is totally at variance with the observed effects of small streams which arise from masses of melting ice. The necessary operations of small streams which transport solid matter, as sand and gravel, in considerable quantities is, the damming up of their own channels and the wearing of new ones, differing in direction from the first; the carrying away of their own depositions in times of high water, and the redeposition of them in other places. In short, the formations of banks of irregular figure, and moderate dimensions in contradistinction from uniform and level strata, is strikingly characteristic of the action of the streams which must have arisen from the melting of the former widespread glacier. The idea that such streams could have laid down strata of but few feet in thickness, and yet extending for many miles with a nearly uniform character and thickness, is not to be thought of. It is plain we must look to some other mode of formation. These features seem to point to the action of a broad stream of water, whose width corresponded somewhat with that of the present lakes; whose direction was the same as the strike of these layers of soil; and whose current flowed with a moderate velocity.

(2) Evidence of the former connexion of Lakes Erie and Michigan in their southern parts. By consulting a map of this region, it will be observed that the valley of the Maumee river, the southwestern tributary of Lake Erie is nearly continuous with that of the St. Joseph, the southwestern tributary of Lake Michigan. The water shed between these two physical sections is almost imperceptible, rising but few feet above the surrounding surface. These two valleys may be regarded as virtually forming but a single one, which connects the southern parts of the two lakes in question. The courses of the tributaries of these rivers also show the fact, that there is here a walley or depression considerably lower than the country to the north, and that in case of a rise of the surfaces of the two lakes, the waters would flow between them through this valley, before it would overflow the lower peninsula of Michigan. Upon this point, the direction of the bands of openings and timbered land has an important bearing. As already stated, these, generally speaking, run nearly parallel to the Maumee river, and consequently parallel to the axis of the valley. This is an important fact. Assuming that a broad arm of water formerly connected the lakes, and that through this, the waters of the then decomposing drift material, heavily charged with sediment, were flowing, the phenomena which we see today would be the natural result. A gradual settling of the region, through which a wide stream of water, heavily laden with debris, was flowing, must have laid down deposits with considerable regularity in the direction in which they flowed. This explains one very characteristic feature of this region. There is another fact, that of the occurrence of the stone ridge mentioned in (5), which also strengthens this hypothesis. If we study carefully the effects of the lake currents to day upon the islands, and especially those in the western part of Lake Erie, we see that they are subjected to a constant wearing away, and that in a comparatively short period they must entirely disappear. And

in like manner, when the former connecting arm between Lakes Michigan and Erie existed, it is not improbable that many islands were found in its waters. The eroding effect of a current containing large quantities of debris, would be much greater than that of one comparatively destitute of it. If islands existed, they must have been worn away rapidly. Upon these assumptions, we may look upon the ridge in question as having been an island rising but slightly above the surface of the water, or as a shoal; and around which the former currents flowed, while they wore it away, and deposited in the shallow water the layers of drift material which we see today.

(3) Evidence of the former level of the lakes. Under this head may be presented facts which seem to entitle this to rank as an established fact, rather than a hypothesis. The evidences in its favor are numerous and decisive. (1) Lake Ridges. In traversing the present shores of the lakes, ridges of sand are frequently observed. They are usually at some distance from the water, and are but few feet in height. They can hardly be ascribed to the action of waves upon the beach; nor can they be regarded as the former lake banks. The evidence furnished by their structure has caused them to be regarded by geologists as of submarine origin; as having been formed beneath the water, but near the shore, by lateral currents. They are found numerously along the shores of the better explored portions of the lakes. Col. Whittlesey (Smithsonian Contributions No. 197) mentions four in Northern Ohio running rudely parallel to each other and to the present shore of the lake. The same has been observed in New York, and Canada, upon the shores of Lake Ontario, where some points rise more than seven hundred feet above the present lake level. They are also found in many other localities. In this connexion we will now mention those in the Maumee Valley. One has a remarkably distinct outline during a large part of its course. It is readily traceable, with slight interruptions, for a distance of more

than one hundred miles. Other similar ridges, but of shorter lengths and less well defined outlines, are found further from the center of the valley. This fact corresponds well with those in Northern and North-Eastern Ohio, where the distinctness of their features gradually diminishes as we recede from the lake. The fact that such a ridge exists, and that it extends in a line so nearly connecting the contiguous parts of the neighboring lakes, seems to leave little doubt of the truth of this hypothesis, and especially so, when supported by corroborative facts. In all of the ridges, layers of fine gravel and water-washed sand are found. The same fact has also been mentioned respecting the strata in N. W. Ohio. (2) Let us see how the features observed in the Maumee valley and in that of the St. Joseph may be explained on the assumption of the gradual receding of the lakes. We have seen that layers of drift material, clay, sand and gravel, extend under the waters of the lakes for an unknown, but yet considerable distance. The sections passed through in boring for artesian wells upon the shore of Lake Erie, prove that this fact also here holds true. If now a gradual receding of the waters is still going on, these successive layers will be gradually laid bare, and will thus be changed into dry land. The character of the land thus formed would depend primarily upon that of the previously existing submerged surface. If this was a clay stratum, extending beneath the water, the same feature would characterize it after its emergence. There are indeed modifying influences, which might partially change its original features. The annual decomposition of vegetation for a period of many years, would cover it with a layer of vegetable mould, such as we find on the surface of the timbered belts already mentioned. The winds would transport sand from neighboring localities over the clay stratum, and thus partially change its original character; and the transporting operation of streams might aid in effecting the same result. In the case of the emergence of a stratum of sand, these

modifying influences would operate to a greater extent than in one of clay. The winds would work a much greater unevenness in its surface than would be the case in the former instance. Its tendency would be to form ridges and depressions corresponding to what we now see in N. W. Ohio. A more complete correspondence between necessary results and assumed conditions could hardly be desired. Travelling upon one of these lake ridges, one may truly think of the long past, but geologically speaking recent time, when the waters of the lake washed the gentle elevation which now forms a natural highway. — It may be objected to the theory proposed respecting the mode of formation of the bands of openings and timbered land, that it is improbable that strata should crop out for such long distances as must here be assumed. In reply, it may be stated, that even now, with clay strata of the depth which are known to exist upon the shore, and with the gentle slope which these shores usually present, bands of different soils might still be formed by a receding of the waters; and indeed we have reason to believe that they are now forming. The flatness of the surface in the Maumee Valley, and the sluggish course of the northern and southern tributaries of that stream, show that when it formed a part of the floor of the former lake, it was characterized by the same evenness as it shows at the present day. (3) Passing now to the region upon the southern and southeastern shores of Lake Michigan, we find the same testimony for the former level of its waters. The divisions of openings and timbered land in this region, however, have less regularity than in the Maumee Valley. The reason for this is obvious. The prevailing direction of the wind being from the west and north, the sandy stratum which is now in process of emergence is exposed unsheltered to their full force. The sand is thus carried to comparatively great distances inland, and by its encroachments upon bands of timber, tends to obliterate to a considerable extent the regularity which would otherwise exist. And so

as we go away from the immediate shore of the lake towards the east and southeast, we find that this same disturbing influence operated in earlier periods; and as a result, we have a much less regular distribution of the two sections of land, and a much less degree of parallelism to each other and to the axis of the great valley in which they were once situated. This influence of the winds would also tend to cause the gradual transition noticed between the two kinds of surface. Thus we are enabled to discern the former level of the lakes and the gradual and slowly operating conversion of a portion of their bottoms into dry land, by simply observing phenomena which are now in progress, and regarding the forces acting today as having been in uniform operation during a long period. (4) Causes of the receding of the lakes. Upon this interesting question geologists are much divided in opinion. Some urge that it is due to the draining off of the former wide-spreading inland sea merely by a continental elevation; that the present lakes are only the remains of a body of water which formerly covered a vastly greater area than at present. To a certain extent, this theory is undoubtedly true. So long as the waters stood above the water-shed which separates the lake basin from any of the adjacent physical sections, no other cause is necessarily assumed; this alone is entirely competent to produce the given results. And indeed if no evidences of disturbance existed in the lake basin, if we had no proof that elevations or depressions of the bottoms of the lakes or of the shores had occurred, this cause would still be sufficient. It is an acknowledged fact, that the Niagara river has been gradually wearing away for many thousands of years towards Lake Erie; and examples of the eroding influence of the immense mass of water which hourly rushes through its channel are frequently observed. And in the absence of evidence of disturbance in the crust, it might be urged that this cause was the only one operating in the reduction of the lake area; and that after a sufficient length of time

had elapsed for the complete developement of this slowly acting agency, instead of the present lake basins, we would have a series of long basin-shaped valleys, as the site of the present lakes, and these valleys connected by deep gorges, sach as the present outlets would present, if worn down to a level with that of the deepest parts of the lake basins themselves. But evidences of disturbance do exist, and we are warranted in looking for a more efficient and rapidly operating cause than that just considered. Not only in the mineral regions and trap dykes of Lake Superior are these evidences to be seen, but also in the level and apparently undisturbed shores of the southern lakes. At Chicago, the sinking of shafts for artesian wells has revealed the fact, that a fault of about one hundred and fifty feet exists upon the southwestern shore of Lake Michigan, and that the rocky stratum at a distance of one mile from the lake shore, lies about one hundred and fifty feet higher than upon the shore. This fact seems to favor the hypothesis of depression. It is much more natural to suppose that the adjacent parts of the lake sunk to that depth, than that the whole surrounding region upon the shore was raised. The pressure upon its floor of such an immense mass of water, entirely destitute of lateral support such as is possessed by land, and especially by rocky strata, is an element which ought not to be left out of the account. And the bearing of the strata farther from the shore, seems to show that the fault at this point may be much more reasonably referred to a sinking, than to an elevation of the crust. Another locality worthy of notice in this connexion is that at Sandusky, upon Lake Erie. The presence of the gypsum beds is one of the evidences here furnished of former disturbance. Assuming that the formation of gypsum is due to igneous action, and that the earth's interior furnished the supply of heat, this fact might be accounted for upon either of two theories in question. Either the disturbing force might have operated from within to effect an upheaval of the surface, and a conse-

quent fracturing of it; or a sinking of the floor of the lake might have fractured the surface at the shore, where a less degree of depression was suffered. The position of the strata at Sandusky and for many miles inland, seem also to favor the latter hypothesis. If we adopt the former hypothesis, we must assume that elevation has proceeded unequally between the bottom of the lakes and their shores; since, if this assumption were not made, no difference in the relative level of the two would result. We would have merely an elevation of the entire lake with its shores, and the latter would stand at the same level above the surface of the water, after the elevation, as before. It is necessary to assume that the shores have been elevated the more rapidly. Admitting that the solid crust of the earth extends to a comparatively small distance toward its interior, the necessary consequence seems to be in favor of the sinking process. The difference in the thickness of the crust between depressions like the basins of the lakes, and the elevated country upon their shores, although small, is not a vanishing quantity. A difference of one fifth of a mile is not to be disregarded. The crust in such places must be perceptibly weaker than in others, and hence would yield more readily to pressure whether from above or below. The results which follow from these suppositions may be applied to the question under discussion. If the region of the lakes has been, and is now being subjected to a pressure from within; — that is, if an elevation has been taking place, it follows that this elevation ought to have operated most actively in the floor of the lakes; that they must have been raised more than the shores; and that, therefore, the lakes would have been spread over a larger area, instead of suffering a contraction. But on the other hand, if a pressure from without has been in operation, the results would correspond to those which we know have occurred. If this force consisted in the gradual contraction of the earths crust, the greater effect would be in the basins. The lateral pressure of the stronger shores would

tend to deepen the already existing depressions. The same result would also take place, if the pressure of the weight of water be assumed as the principle active agent. A sinking of the lake basins themselves would extend to their outlets, although in a less marked degree, and thus the phenomena of the gradual draining of the lakes, as well as the fact that their centers are considerably lower than their outlets, would be satisfactorily explained. The facts as explained by this hypothesis also correspond with analogous phenomena in other localities. The theory of gradual depression does not entirely ignore the partial cooperation of shore elevation. It is not improbable that the latter participated to some extent in producing the observed effects. Indeed, it may be questioned whether the one can occur without being in some degree accompanied by the other, and the adoption of either theory must merely signify a preponderance in the amount of influence produced. In the present state of our knowledge, all the theories bearing upon this point must be considered as hypothetical. A long continued series of well conducted observations is indispensable, before exact and undoubted results can be gained. To future investigations must we confidently look for the complete solution of the interesting problems connected with the geological history of the lakes; and the difficulties which the scientific investigator encounters, will be richly rewarded by the establishment upon a firmer basis, of some of the most important laws of physical geology.